

AD-A051 330

AIR FORCE ACADEMY COLO  
THE UTILIZATION OF SIDE LOOKING AIRBORNE RADAR (SLAR) IN THE AN--ETC(U)  
SEP 77 C L SMITH, A P TRIBBLE  
USAFA-TR-77-13

F/G 17/9

UNCLASSIFIED

NL

| OF |  
AD  
A051 330



END  
DATE  
FILMED

4-78

DDC



AD A051330

AD No. \_\_\_\_\_

DDC FILE COPY

12

USAFA-TR-77-13

# THE UTILIZATION OF SIDE LOOKING AIRBORNE RADAR (SLAR) IN THE ANALYSIS OF KARST TOPOGRAPHY

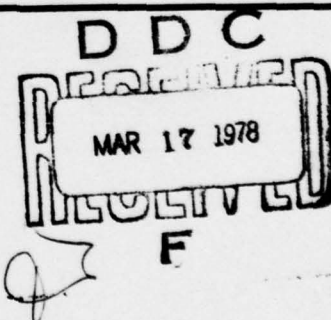
MAJOR CHARLES L. SMITH  
Associate Professor

MAJOR A. PAUL TRIBBLE  
Associate Professor

DEPT OF ECONOMICS, GEOGRAPHY  
AND MANAGEMENT  
USAF ACADEMY, COLORADO 80840

SEPTEMBER 1977  
FINAL REPORT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED



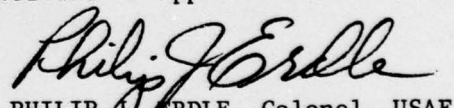
DEAN OF THE FACULTY  
UNITED STATES AIR FORCE ACADEMY  
COLORADO 80840

Editorial Review by Lt Col Elser  
Department of English  
USAF Academy, Colorado 80840

This research report is presented as a competent treatment of the subject, worthy of publication. The United States Air Force Academy vouches for the quality of the research, without necessarily endorsing the opinions and conclusions of the author.

This report has been cleared for open publication and/or public release by the appropriate *Office of Information* in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service.

This research report has been reviewed and is approved for publication.

  
PHILIP J. ERDLE, Colonel, USAF  
Vice Dean of the Faculty

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER <b>14</b> USAFA-TR-77-13	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) <b>6</b> THE UTILIZATION OF SIDE LOOKING AIRBORNE RADAR (SLAR) IN THE ANALYSIS OF KARST TOPOGRAPHY.	5. TYPE OF REPORT & PERIOD COVERED <b>9</b> FINAL REPORT.	
7. AUTHOR(s) <b>10</b> Major Charles L. Smith <del>and Major</del> A. Paul/Tribble	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Economics, Geography and Management United States Air Force Academy, Colorado 80840	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS DFEGM USAF Academy, Colorado 80840	12. REPORT DATE <b>11</b> September 1977	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. NUMBER OF PAGES 33 <b>12</b> 35P	
	15. SECURITY CLASS. (of this report)	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  Approved for Public Release; Distribution Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  <div style="text-align: right;"><b>DDC</b> <b>RECEIVED</b> <b>MAR 17 1978</b> <b>F</b></div>		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Side Looking Airborne Radar (SLAR), Karst Topography, Electromagnetic Spectrum, Sinkholes, Remote Sensing, Geomorphology		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Characteristics of mechanical and synthetic radar systems are reviewed. Signature elements of karst topography such as a vertical drainage pattern, knobs, and sinkholes are identified for Side Looking Airborne Radar (SLAR) imagery. SLAR imagery of the Kentucky Pennyroyal and karst areas in Florida is presented with the signature elements highlighted. Applications of SLAR imagery to the identification and mapping of karst areas in physically, climatologically, or politically inaccessible areas is addressed.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED  
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

011 550 JUB

# TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION. . . . .	4
KARST . . . . .	8
SIDE LOOKING AIRBORNE RADAR (SLAR). . . . .	12
APPLICATIONS OF SLAR. . . . .	14
EXAMPLES OF SLAR IMAGED KARST TOPOGRAPHY. . . . .	17
APPENDIX. . . . .	25

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	<input type="checkbox"/>
BY	
DISTRIBUTION/AVAILABILITY CODES	
SPECIAL	
A	

## LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	CLASSIFICATION OF REMOTE SENSORS BY THE TYPE OF FIELD SENSED. . . . .	4
2	TYPICAL FEATURES OF BOMB/NAV RADAR, MECHANICAL SLAR, AND SYNTHETIC SLAR . . . . .	30

## LIST OF FIGURES

### Figure

1	THE ELECTROMAGNETIC SPECTRUM AND APPROXIMATE SPECTRAL REGIONS OF REMOTE SENSORS. . . . .	6
2	SINKHOLES IN A ONE-SQUARE MILE AREA OF ORANGE COUNTY, INDIANA . . . . .	10
3	KARST TOPOGRAPHY. . . . .	13
4	SLAR IMAGE OF PREDOMINANTLY VERTICAL AND LATERAL DRAINAGE PATTERNS IN KENTUCKY . . . . .	18
5	SLAR IMAGE OF KNOBS IN THE VICINITY OF PARK CITY, KENTUCKY. . . . .	20
6	SLAR IMAGE OF EXCESSIVELY LARGE SINKHOLES NORTH OF PANAMA CITY, FLORIDA . . . . .	22
7	LARGE SCALE SLAR IMAGE OF SINKHOLES IN TAMPA, FLORIDA. . . . .	23
8	BEAM WIDTH ERROR. . . . .	26
9	PULSE LENGTH ERROR. . . . .	27
10	TYPICAL LATERAL SLAR COVERAGES. . . . .	33

## INTRODUCTION

The field of remote sensing has received increased attention only in the past few decades. The field covers a very broad area, and is best defined as dealing with the, "...acquisition of physical data of an object without touch or contact."<sup>1</sup> Systems of classifying the various sensors into subcategories use both the nature of the force field sensed and the frequency interval in which the sensor operates (Table 1).

TABLE 1<sup>2</sup>

### CLASSIFICATION OF REMOTE SENSORS BY THE TYPE OF FIELD SENSED

<u>Field</u>	<u>Sensors</u>
Gravitational (Force)	Gravity Meter
Magnetic	Magnetometer
Pressure	Seismography
Electromagnetic	Gamma-Ray Spectrometer
	Ultraviolet Radiometer
	Camera
	Infrared
	Microwave Radiometer
	Radar

A great deal of work is being conducted in all areas of the electromagnetic spectrum. This report is concerned with the radar

---

<sup>1</sup>Joseph Lintz, Jr. and David S. Simonett, Remote Sensing of Environment (Reading, Mass.: Addison-Wesley Publishing Co., 1976), p. 1.

<sup>2</sup>Louis Dellwig, et al., Radar Remote Sensing for Geoscientists--Short Course Notes (Lawrence, Kansas: University of Kansas, Center for Research, Inc., and Division of Continuing Education, June 1972), p. 1-3.

portion of that spectrum and specifically with the use of radar imagery to identify topography. After presenting a paper on the use of radar in land use mapping, Dr. Floyd Henderson commented on a need for research in the utilization of remote sensing imagery to identify geomorphic features within various landscapes.<sup>3</sup>

Radar occupies only a small segment of the electromagnetic spectrum between Infrared and VHF (Figure 1). For the purpose of this report, radar refers to any active mechanical or synthetic electromagnetic device used for remote sensing.<sup>4</sup> This does not include sensing with passive microwave systems, which have been used on occasions with varying success to measure subsurface discontinuity and identify karst topography.<sup>5</sup> Active systems emit energy and record the amount of energy returned to the sensor. Passive systems do not emit energy and record only the energy inherent in the object being sensed. The information in this report applies primarily to commercial systems, and does not address classified military systems.

The high resolution radar systems presently in regular use

---

<sup>3</sup>Floyd Henderson (Pers. Comm. 1977)

<sup>4</sup>Robert G. Reeves, ed. in chief, Manual of Remote Sensing (Falls Church, Virginia: The American Society of Photogrammetry, 1975), p. 41.

<sup>5</sup>For example, J. M. Kennedy, "A Microwave Radiometric Study of Buried Karst Topography," Geological Society of American Bulletin 79 (1968): 735-742.



for remote sensing are designed to collect data from an area perpendicular to the flight path of the aircraft. This type radar sensing system is, therefore, termed Side Looking Airborne Radar (SLAR). Specific characteristics of SLAR systems are presented in the third section of this report. Definitions of terms inherent to SLAR systems and karst topography are presented in the Appendix.

Geographers have used remote sensing devices to analyze topography with a great deal of success. D. K. Erb and P. Eng described the geomorphology of Jamaica by extensively studying aerial photographs of large areas of karst.<sup>7</sup> The application of SLAR to the study of terrain and geomorphology is also common, though it has not been used to identify areas of karst. Studies in Panama, Venezuela and Brazil are examples of geomorphic use of SLAR.<sup>8</sup>

In this paper, we will discuss the possibility of using SLAR to identify karst topography. To accomplish our objective, we will present the causes and major features of karst topography as well as the basic characteristics and applications of the sensor system. A concluding section presents examples of SLAR imaged karst topography.

---

<sup>7</sup>D. K. Erb and P. Eng, "Geomorphology of Jamaica," Photogrammetric Engineering 34 (1968): 1148-1160.

<sup>8</sup>Harold C. MacDonald, "Geologic Evaluations of Radar Imagery from Darien Province, Panama," Modern Geology 1 (November 1969): 1-63.

## KARST

The term [karst] comes from the narrow strip of limestone plateau of Yugoslavia and adjacent portions of Italy bordering the Adriatic Sea, where there exists a remarkable assembly of features dependent upon sub-surface solution.<sup>9</sup>

Fully developed karst is localized in relatively small areas, but is a phenomenon that exists in widely scattered locations. For example, significant areas of karst can be found in portions of France, Spain, Mexico, Jamaica, Puerto Rico, Cuba, New Guinea, Celebes, Southeast Asia, and Australia, and in all states of the United States.

Certain rocks such as limestone, chalk, mark, dolomite, and gypsum are extremely susceptible to solution by water. The solution of these rocks has resulted in a series of distinct landforms and features which have been grouped together under the term karst. There are four basic requirements for the formation of karst topography: First, there must be a soluble rock, preferably limestone near the surface. Second, the rock must be thinly bedded, dense and highly jointed. It is extremely important that the rock be jointed, and not merely porous. If the rock is highly porous the water will percolate en masse through the rock, and will not be concentrated along restricted lines. Third, valleys in the areas must be entrenched so that there is a downward motion of groundwater;

---

<sup>9</sup>William D. Thornbury, Principles of Geomorphology (New York: John Wiley and Sons, Inc., 1969), p. 303.

and finally, there must be at least moderate rainfall.<sup>10</sup> As drainage systems begin to form in areas of water soluble rock, an underground movement of water develops along the joints and bedding plain of the rock. Gradually, underground waterways begin to form as the solution of the rock continues. Sinkholes or sinks, which are by far the most common features of youthful karst areas, also begin to develop. The most common type of sinkhole is the funnel-shaped doline, which is formed by the slow solution of the rock surface just below the soil with no disturbance to the rock itself. Another type of sink is the deep, steep-walled feature formed by the collapse of underground caverns. In the Yucatan these sinks are called cenotes while Thornbury refers to smaller examples of these features found in Florida as ponors.<sup>11</sup> Often streams will drain into sinks which are then called swallow holes, or the water of a stream may simply sink into the ground along the stream bed.<sup>12</sup> The underground streams and waterways may rise to the surface many miles from the swallow hole as a spring or seep. These springs or seeps may be located in the same valley as the swallow hole or in another valley. In areas of gently dipping or nearly horizontal beds of soluble rock, the landscape is often covered with sinkholes and the surface is referred to as a karst plain.

---

<sup>10</sup>Ibid., pp. 305-306.

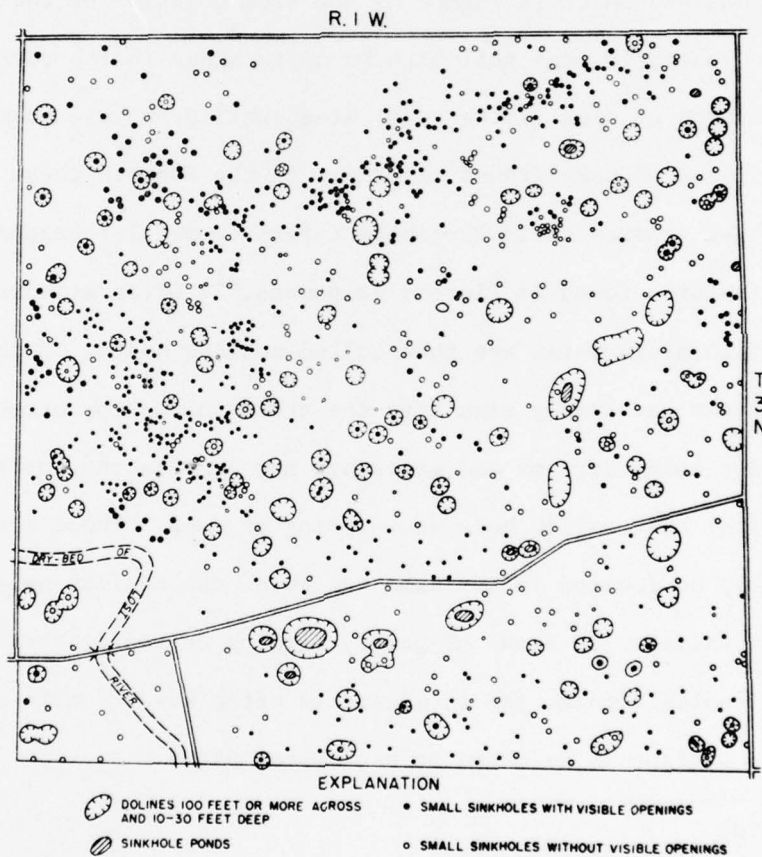
<sup>11</sup>William D. Thornbury, Regional Geomorphology of the United States (New York: John Wiley & Sons, Inc., 1965), p. 48.

<sup>12</sup>R. Kay Gresswell, Physical Geography (New York: Praeger, 1967), p. 132.

Some karst areas contain thousands of sinkholes. In one square mile area of Orange County, Indiana, Malott found 1,022 sinkholes (Figure 2). One hundred twenty one of these were at least one hundred feet in diameter.

Figure 2<sup>13</sup>

SINKHOLES IN A ONE SQUARE MILE AREA  
OF ORANGE COUNTY, INDIANA



<sup>13</sup>Thornbury, p. 309.

As sinkholes expand they unite into larger features called compound sinkholes. In some areas the compound sinkholes form large structures called uvalas which may be one-half mile in diameter. A special form of sinkhole is the polje. This is an elongated basin with a flat floor and steep walls created by the solution modification of down faulted or down folded limestone blocks. These features may be water filled and up to forty miles long.<sup>14</sup>

In conjunction with these larger sinkholes, the few surface streams which do occur may flow for only a short distance and then disappear. "In areas of karst topography of tuffaceous volcanics, the detectable drainage pattern is sparse and often sporadic."<sup>15</sup> The typical drainage of a karst landscape is marked by only a few short streams with most of the runoff entering sinks or swallow holes. Lateral drainage patterns, which are characteristic of non-karst areas, contain a much greater number of streams of greater lengths.

Many of the sinks serve as nodes for areas of internal drainage. At this stage in the development of karst topography, it is common for an area which receives thirty to forty inches of precipitation to be covered with vegetation commonly associated with much drier areas. This is caused by the lack of moisture available

---

<sup>14</sup>Fritz Machatschez, Geomorphology, translated by D. F. David (New York: American Elsevier Publishing Co., 1969), p. 104.

<sup>15</sup>Louis F. Dellwig, et al., Radar Remote Sensing, p. 5.1-3.

at or near the surface. As solution of the rock continues, portions of the surface covering underground waterways are removed. Due to the collapse of the roofs of caverns, depressions, natural bridges, and natural tunnels are formed. Additional solution will result in segments of the soluble rock being left on top of more resistant rocks as residual hills known as hums, cones, haystack hills, or knobs. Hums may rise as much as nine hundred feet above adjacent areas. Eventually the hums are surrounded by alluvial plains, and lateral drainage will replace vertical drainage.<sup>16</sup> Figure 3 shows many of the karst features described above.

#### SIDE LOOKING AIRBORNE RADAR (SLAR)

SLAR has several advantages not found in other remote sensing systems. For example, SLAR provides a great amount of aerial coverage on one image, often at a constant scale. An interpreter can delineate as much hydrological detail from a SLAR image with a scale of 1:200,000 as from a 1:62,500 scale topographic map, and a single SLAR image can provide as much as one hundred miles of lateral coverage.<sup>17</sup> Radar cannot resolve detail as well as the eye, but it can penetrate darkness, haze, fog, rain and snow.<sup>18</sup>

---

<sup>16</sup>Thornbury, p. 339; M. M. Sweeting, "Karst" in Rhodes W. Fairbridge, ed., The Encyclopedia of Geomorphology (New York: Reinhold Book Corporation, 1968), pp. 582-587.

<sup>17</sup>Roger McCoy, "Drainage Network Analysis with K-Band Radar Imagery," Geographical Review 59 (1969): 493-494.

<sup>18</sup>William P. Waite, "Historical Development of Imaging Radar," Remote Sensing of the Electromagnetic Spectrum 3 (July 1976): 5.

## KARST TOPOGRAPHY

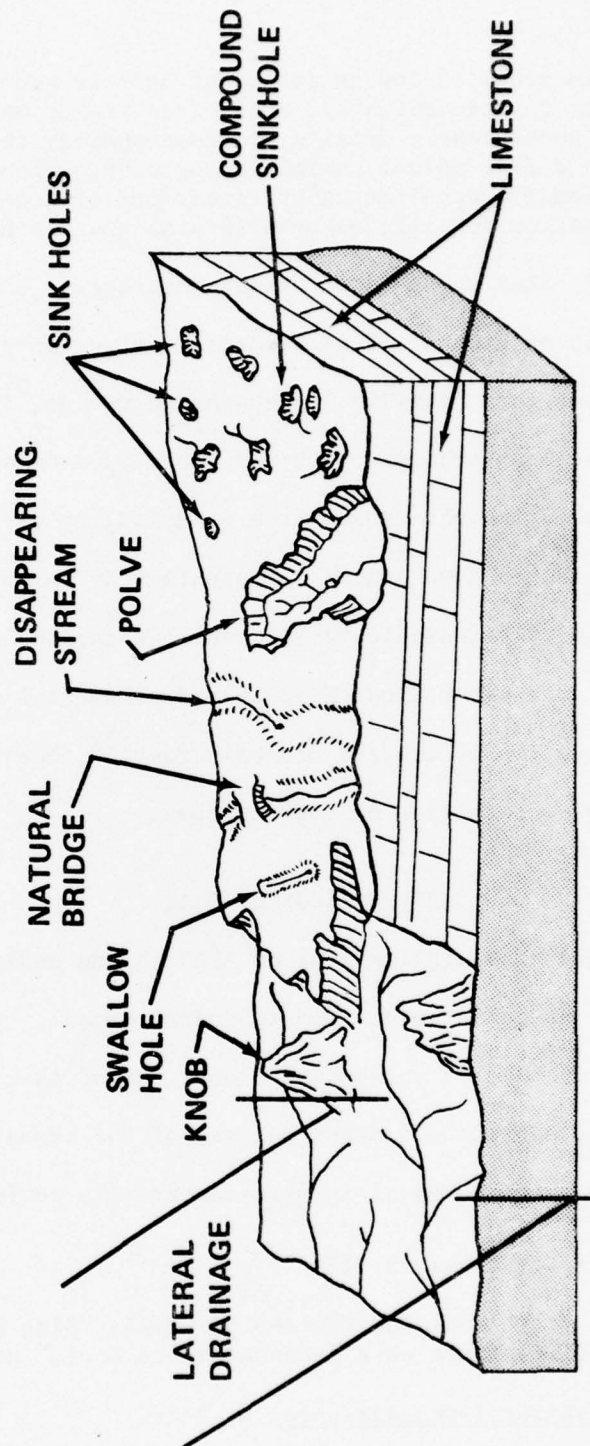


Figure 3<sup>19</sup>

<sup>19</sup>C. L. Smith, "The Application of Side Looking Airborne Radar and Multi-Band Photography to the Study and Analysis of Karst Topography," 1972, University of Georgia, unpublished report.

In areas of low relief or of uniform ground cover (such as in rain forests), SLAR often yields more information about subtle details of geomorphology than can be gained from normal aerial photography, which is traditionally acquired under conditions of high sun illumination (usually between 10 a.m. and 2 p.m.).<sup>20</sup>

In 1967, SLAR was used to obtain coverage of a 17,000 square kilometer area of Panama. This project involved only six hours of imaging time in a heavily cloud-shrouded region.<sup>21</sup> This result could not have been achieved with any other type of sensing system.

The resolution obtainable from SLAR imagery varies between systems, but ranges downward from approximately seventy-five feet. Some SLAR imagery releasable to the public today has a resolution of ten feet. One report indicates that experimental systems have obtained resolution of two and one-half feet.<sup>22</sup> See the Appendix for additional information on SLAR systems.

#### APPLICATIONS OF SLAR

There are many applications of SLAR to the analysis of geomorphology. "By obscuring minor and redundant detail, by imaging large areas, and by producing a two-dimensional output that closely resembles a pseudo three-dimensional map of the terrain, radar imagery provides patterns of information broadly conforming to

<sup>20</sup>Robert G. Reeves, p. 13.

<sup>21</sup>Louis F. Dellwig and Charles Burchell, "Side Look Radar-- Its Uses and Limitations as a Reconnaissance Tool," unpublished.

<sup>22</sup>Multisensor Reconnaissance, p. 3-23.

grossly distinct areal differences, i.e., landform regions."<sup>23</sup> It is these patterns of landforms which allow SLAR imagery to be used in solving a wide variety of resource inventory and terrain evolution problems. Geomorphologists have used it to analyze stream networks, stream meanders, and regional slopes. They have additionally used it to create geologic maps and for identification of major fracture zones not apparent on large-scale imagery.<sup>24</sup>

Geologists have also used SLAR in their research work, with one or more objectives in mind: correlation of outcrops; determination of stratigraphic sequences; delimitation of lithologic units; or determination of geologic structure.<sup>25</sup>

Because of its good weather penetrating capability, SLAR is one of the best sensors for obtaining data in humid or cloud covered areas such as dense rainforests or cloud forests. Recent radar surveys for Panama, Venezuela, and Brazil mapping projects were in areas almost always covered by clouds, rendering photography virtually worthless.<sup>26</sup>

Simonett states that, "In geomorphic studies, one of the most obvious and readily applied uses of radar imagery is to obtain

---

<sup>23</sup>Louis F. Dellwig, et al., Radar Remote Sensing, p. 4.1-1.

<sup>24</sup>Manual of Remote Sensing, p. 14.

<sup>25</sup>Harold C. MacDonald, "Use of Radar in Geology," Remote Sensing of the Electromagnetic Spectrum 3 (July 1976): 94.

<sup>26</sup>Manual of Remote Sensing, p. 399.

a visual and essentially planimetric presentation of the drainage network, which can be the base for an accurate map."<sup>27</sup> This statement is reinforced in part by recent studies in Panama where SLAR has provided very detailed data concerning drainage basins in dense rainforests.

SLAR also has the capability of enabling the image interpreter to identify areas of karst by their topographic pattern.<sup>28</sup> In some karst areas, drainage patterns are difficult to detect because of their abbreviated form.<sup>29</sup> However, as we will show in the next section, these patterns can be identified on SLAR imagery and appear distinctly different from drainage patterns in non-karst areas. Additionally, it is possible to identify some sinkholes on SLAR imagery. Recall that in the square mile of land represented in Figure 2 there were 121 sinkholes larger than one hundred feet in diameter. Even the oldest SLAR systems have resolution capabilities of less than one hundred feet.

In summary, imagery from a system which is not as advanced as those presently in use, the AN/APQ-69, with a scale of 1:700,000 presents sufficient drainage detail to compute stream lengths,

---

<sup>27</sup>David S. Simonett, p. 67.

<sup>28</sup>Louis F. Dellwig, et al., Radar Remote Sensing, p. 4.1-30; Roger M. McCoy and Anthony J. Lewis, "Use of Radar in Hydrology and Geomorphology," Remote Sensing of the Electromagnetic Spectrum 3 (July 1976): 119.

<sup>29</sup>Louis F. Dellwig, et al., Radar Remote Sensing, p. 4-3.

which could not be obtained from a 1:250,000 topographic map.<sup>30</sup>

This detail would be of tremendous value in the identification of karst in unmapped or little known areas of the world. In areas of dense vegetation, the returns depicted on the SLAR imagery will allow identification of such ground features as sinks, uvalas and poljes. Even advanced stages of karst development, where hums or knobs and lateral drainage occur, can be identified on SLAR imagery.

The capabilities of all weather service and vast coverage combined with the elimination of much needless ground clutter renders SLAR an excellent tool for the identification of topography types, including karst. While it is true that karst is one of the most difficult topography types to identify on SLAR, it can be done by the trained interpreter looking for the signatures of an abbreviated drainage pattern, sinkholes, and/or rounded hills. In short, SLAR serves as a key to open new areas to topographic analysis.

#### EXAMPLES OF SLAR IMAGED TOPOGRAPHY

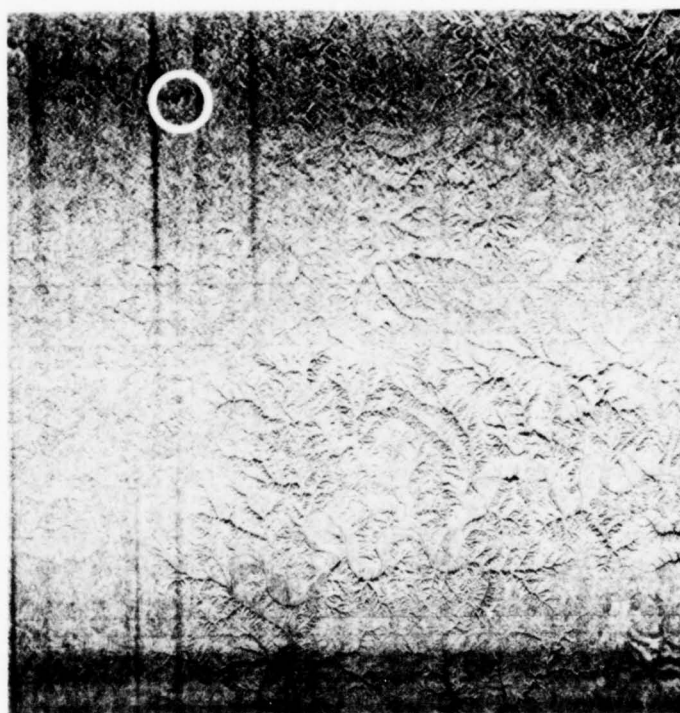
Note in Figure 4 the predominately lateral drainage pattern in the bottom right portion of the image. As one moves up and left from this drainage system, he sees the Kentucky Pennyroyal. This area has tens of thousands of sinkholes, and a predominately vertical

---

<sup>30</sup>McCoy, p. 495.

Figure 4

SLAR IMAGE OF PREDOMINATING VERTICAL  
AND LATERAL DRAINAGE PATTERNS IN KENTUCKY



drainage pattern.<sup>31</sup> This contrast in drainage patterns provides the first indication to the image interpreter that karst topography may be present.

Another signature of several karst areas is the presence of knobs. One of these features is very much in evidence in the top left portion of the image (circled). This formation rises above the surrounding terrain.

Identification of the relatively small sinkholes in the area is precluded by the seventy-five foot image resolution and the 1:600,000 scale. Nevertheless, with the signatures of drainage pattern and knobs, the trained interpreter should be able to identify the area as one of karst topography.

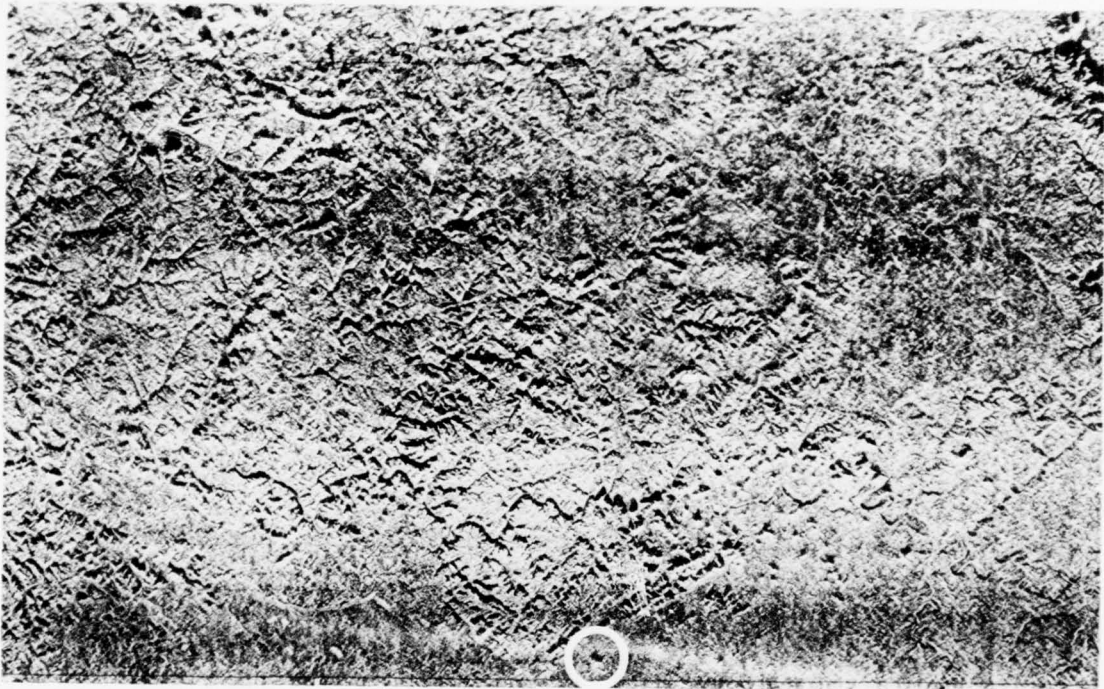
The image portrayed in Figure 5 is of an area immediately north of that shown in Figure 4 (except for the portion of the landscape omitted by the radar holiday). One can easily identify several knobs in the bottom portion of the image. The formation circled in the immediate bottom center is Brushy Knob, a structure 960 feet above sea level and approximately 250 feet above the surrounding area.

The drastic change in drainage patterns between karst and non-karst landscapes is indicated at the bottom of this image. The karst area in the south has a predominately vertical drainage

---

<sup>31</sup>A. K. Lobeck, Geomorphology (New York: McGraw-Hill Book Company, Inc., 1939), p. 144.

Figure 5  
SLAR IMAGE OF KNOBS IN THE VICINITY  
OF PARK CITY, KENTUCKY



system while the more familiar lateral drainage in the north is representative of non-karst areas. The interpreter can easily detect the border between these patterns.

The resolution of the imagery in Figure 6, like that of the previous two images, is seventy-five feet; however, sinkholes are obviously more readily identified in Figure 6. This is a function of the much larger size and nature of sinkholes in Florida. The shallow, funnel-shaped sinks of Kentucky do not present the strong signature of the deeper, steep-sided ponors of Florida. Some of the sinkholes north of Panama City cover several hundred acres.<sup>32</sup>

When SLAR imagery with a ten-foot resolution of the Tampa, Florida area is examined, very small sinkholes can be identified (Figure 7). For example, notice the small size of the sinkholes on the right half of the image when compared to the size of the adjacent racetrack or to the width of the nearby thoroughfares.

SLAR imagery with a ten-foot resolution would, no doubt, reveal the presence of sinkholes in the area of Kentucky covered by Figures 7 and 8. The trained interpreter would then be able to identify three rather than two signature features, indicating with considerable assurance that the area's topography is indeed karst.

As time passes, newer SLAR systems will be developed with even better resolution. With the introduction of these systems, additional signature elements will be developed to aid the image

---

<sup>32</sup>Nevin N. Fenneman, Physiography of Eastern United States (New York: McGraw-Hill Book Company, Inc., 1938), p. 76.

Figure 6

SLAR IMAGES OF EXCESSIVELY LARGE  
SINKHOLES NORTH OF PANAMA CITY, FLORIDA

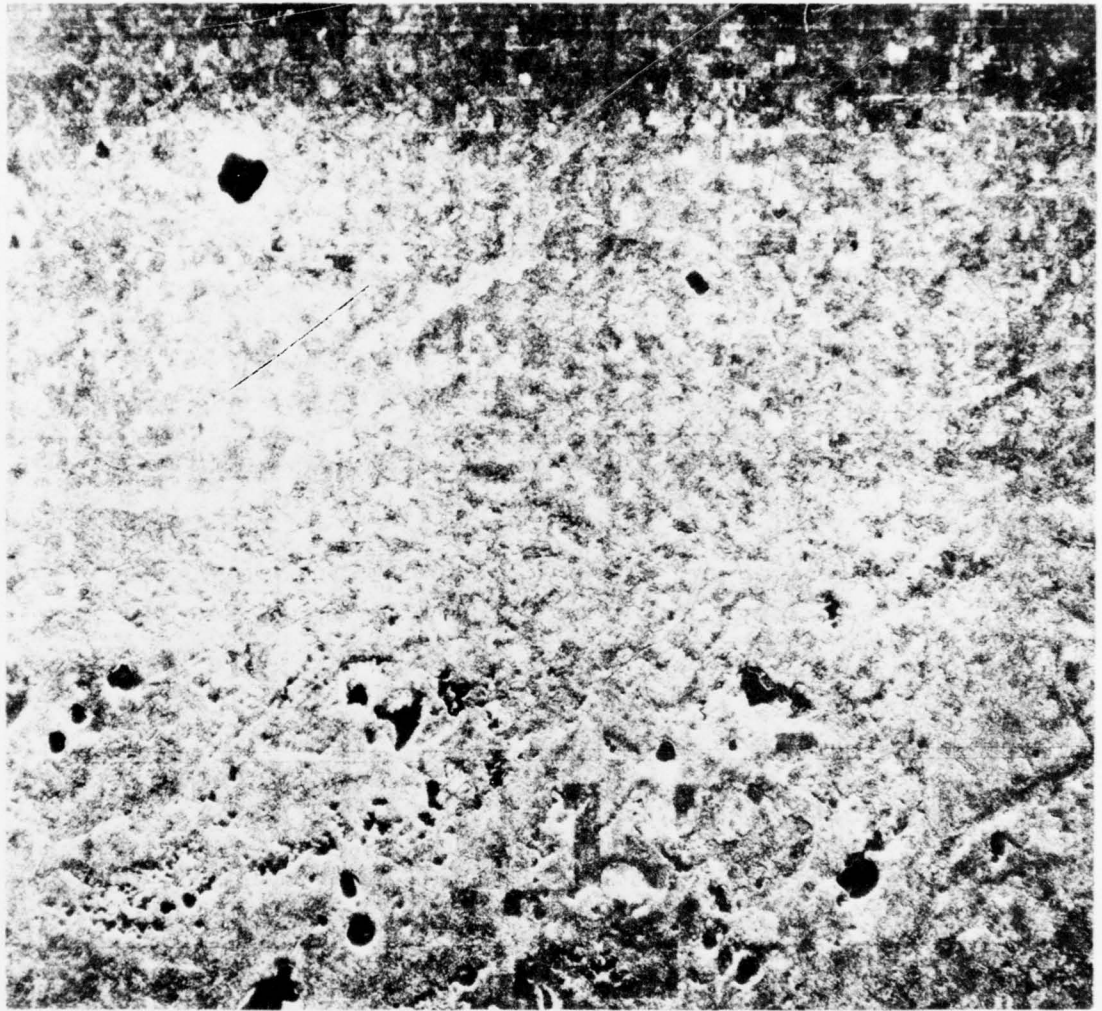
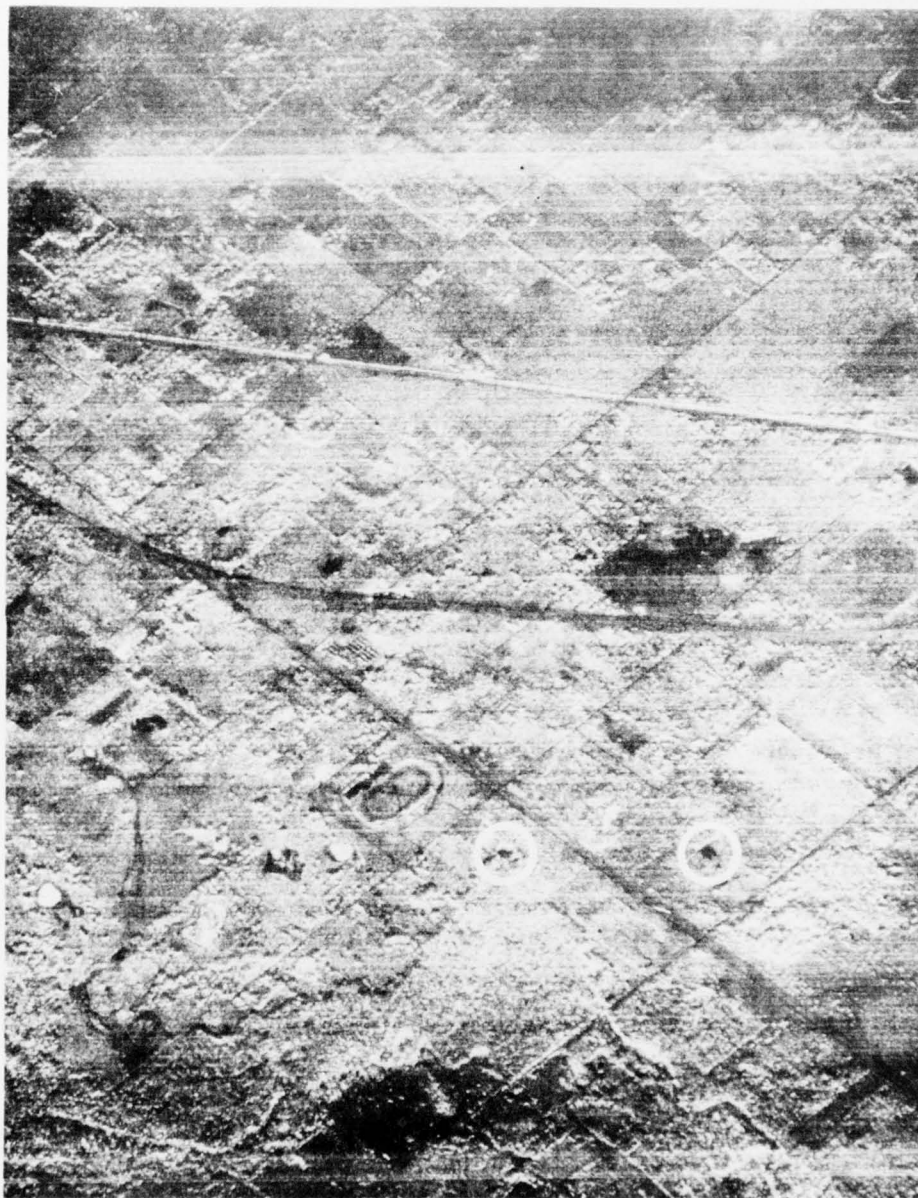


Figure 7

LARGE SCALE SLAR IMAGE OF SINKHOLES

IN TAMPA, FLORIDA



interpreter to pinpoint areas of karst with near one-hundred percent accuracy. Until that day arrives, however, the present systems can be carefully used by the trained interpreter to verify the existence of suspected karst areas and to locate previously unknown landscapes with a high degree of accuracy.

## APPENDIX

### Side Looking Airborne Radar Systems

SLAR provides a remote sensing system with a better weather and haze penetration capability than photography. The traditional radar used for bombing and navigation, commonly called bomb/nav radar, presents sufficient ground detail to interpret several features for very generalized studies. This capability was discussed by Allen Feder in a 1960 article in Photogrammetric Engineering which pointed out the potential uses of radar to distinguish such features as windgaps, ridge and valleys, and faults.<sup>33</sup>

The typical bomb/nav radar system has very good range together with all-weather penetration capability, but very poor resolution. Poor resolution in radar is the result of three factors: beam width, pulse length, and spot size. The width of the radar beam creates an error because as the leading edge of the beam strikes an object and begins its return to the antenna, the center of the beam has not encountered the object. When the trailing edge of the beam has reached the object, the true size of the object has been recorded as well as an error on each side of the object (Figure 8).

Pulse length error is due to the duration of the pulse. As the returning pulse is being recorded, the sweep of the radar set elongates the return in an amount proportional to the length of the pulse (Figure 9).

---

<sup>33</sup> Allen Feder, "Interpreting Natural Terrain from Radar Displays," Photogrammetric Engineering 20 (1960): 620.

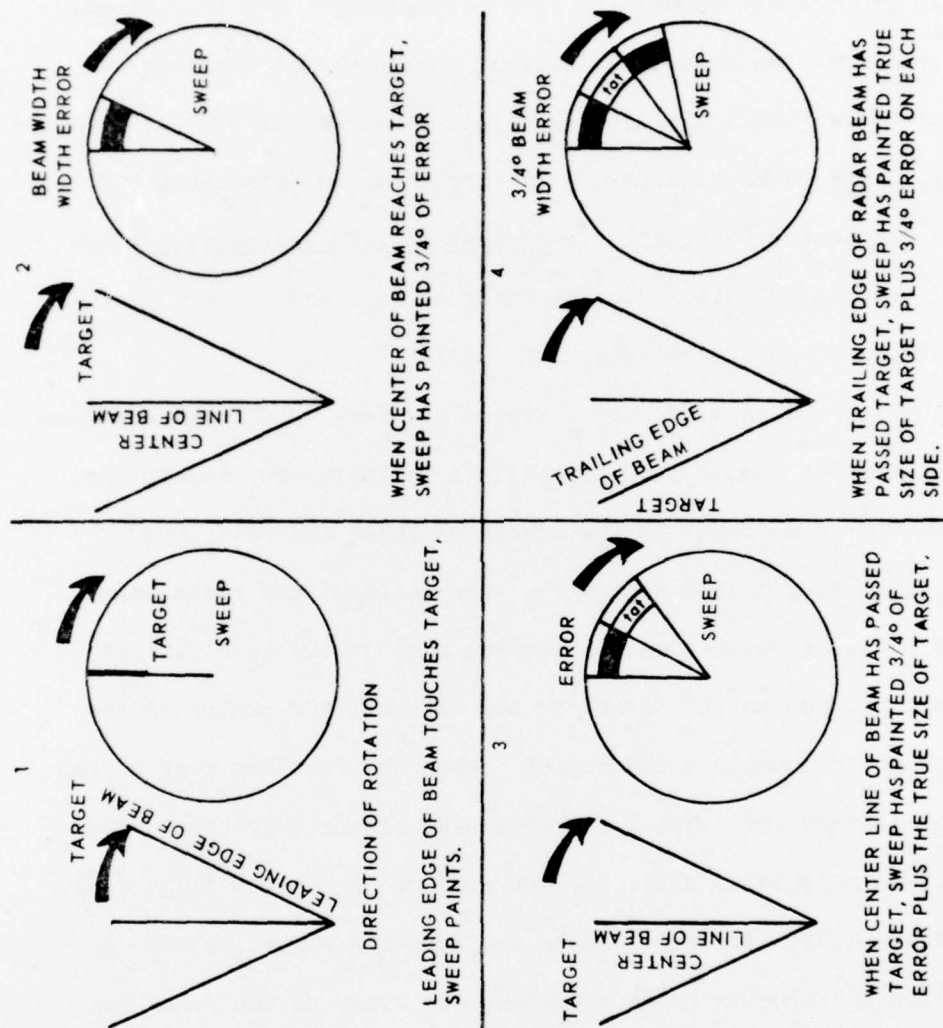


Figure 8<sup>34</sup>

BEAM WIDTH ERROR

<sup>34</sup> Multisensor Reconnaissance (Lowry AFB, Colorado: Armed Forces Air Intelligence Training Center, 1 June 1969), p. 2-16.

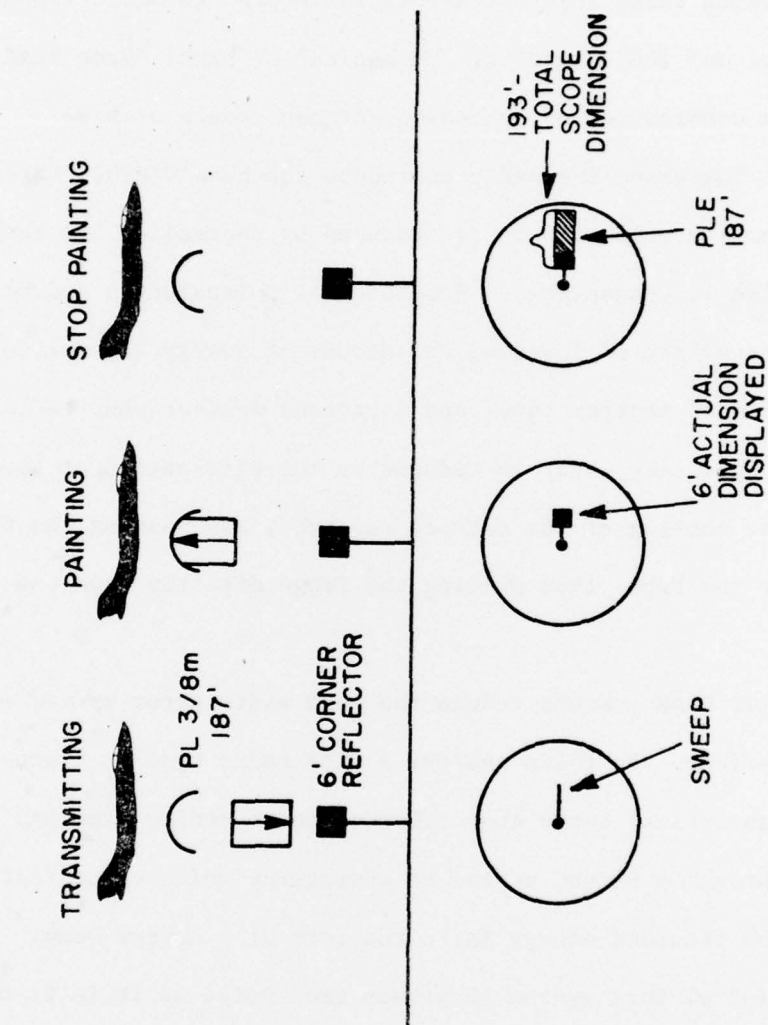


Figure 9<sup>35</sup>

PULSE LENGTH ERROR

<sup>35</sup>Ibid., p. 2-18.

Spot size error refers to the size of the individual dots which make up the phosphorescent coating of the cathode ray tube upon which the radar returns are presented.

In reducing these inherent errors there are two basic approaches, the mechanical and the synthetic. Mechanical or brute force SLAR systems use a combination of increased antenna length or size together with increased frequency to reduce the beam width. Errors resulting from the pulse length are reduced by decreasing the length of time a pulse is transmitted. Reduction of pulse length and beam width have the effect of lowering the amount of energy transmitted, and result in much shorter range and decreased weather penetration capability. Spot size error is reduced by the elimination of the phosphorescent coating of the cathode ray tube, and passing the film directly over the tube, thus placing the image directly upon the film.

Synthetic SLAR systems reduce the beam width error by use of the doppler effect. In these systems a wide radar beam is transmitted, but an optical correlator records the returning beam and focuses it through a narrow series of aperatures which concentrate the beam. The recorded energy is in the form of a narrow beam. Another portion of this system lengthens each pulse as it is transmitted and compresses the pulse as it is returned to the antenna. Spot size is reduced by eliminating the phosphorescent coating on the cathode ray tube and recording the image directly on film.

Synthetic SLAR systems have good range and weather penetration

capability, require smaller antennas than do the mechanical systems and also provide good ground resolution. They do, however, require much more complex electrical equipment and greater amounts of electrical power. Table 2 compares some features of the bomb/nav, mechanical SLAR and synthetic SLAR systems.

Mechanical SLAR most frequently uses wavelengths in what is referred to as the K-band of the electromagnetic spectrum between 0.75 and 2.4 cm. Synthetic SLAR systems commonly operate in the X-band portion of the spectrum, with wavelengths from 2.4 to 3.75 cm.<sup>36</sup>

SLAR systems today are generally restricted to Department of Defense use, however, Westinghouse and Goodyear produce commercial SLAR sets. One Westinghouse commercial set, AN/APN 153, uses pulses of 0.07 microseconds with wavelengths of 0.86 cm and frequencies of 34,850 megahertz (MHz). This is in the K-band of radar.<sup>37</sup> The commercial Goodyear Electronic Mapping System (GEMS) is an X-band radar, with a wave length of 3.1 cm and a resolution of fifteen meters.<sup>38</sup>

One of the earliest military systems, Westinghouse's 1954 AN/APQ-56 Mechanical SLAR system, was used by the Strategic Air

---

<sup>36</sup> Advanced Radar Topographic Application (Ft. Belvoir, Virginia: Raytheon Co.), p. 1.

<sup>37</sup> David S. Simonett, "Remote Sensing with Imaging Radar," Geoforum 2 (1970): 62.

<sup>38</sup> Louis F. Dellwig, et al., Use of Radar Images in Terrain Analysis: An Annotated Bibliography (Ft. Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, 1975), p. 16.

TABLE 2<sup>39</sup>TYPICAL FEATURES OF BOMB/NAV RADAR,  
MECHANICAL SLAR, AND SYNTHETIC SLAR

<u>FEATURES</u>	<u>BOMB/NAV</u>	<u>MECHANICAL</u>	<u>SYNTHETIC</u>
Beam Width	1.5°	0.13°	1.5°
Antenna Length (feet)	4.5	13	5
Frequency (MHz)	9,500- 10,000	35,000- 36,000	9200- 9600
Pulse Length (Micro- seconds)	0.37-5	0.04-0.1	0.06
Range (nautical miles)	100-150	40	40
Spot Size (inches)	0.017	0.001	0.001

---

<sup>39</sup>Multisensor Reconnaissance, pp. 3-3,3-9.

Command. Later, variations of this system were produced by Westinghouse for drone aircraft, and released under the titles of AN/APQ-55 and AN/APQ-86. Additionally, Motorola produced a mechanical system for Mohawk manned aircraft labeled AN/APQ-94. With the exception of an AN/APQ-56 system, none of the early Westinghouse systems has been used for earth-resource-survey purposes.<sup>40</sup>

In 1961, Westinghouse produced the mechanical AN/APQ-97, which has had non-military use in geoscience research. This was the first SLAR imagery that permitted the interpreter to make elevation measurements.<sup>41</sup>

While mechanical SLAR systems were being developed as indicated above, the military was developing synthetic aperture radars (SAR) under military security restrictions at Goodyear, Philco, and the Universities of Illinois and Michigan. Several SAR systems have been developed since the 1950's, including the AN/VPD-1 built by Texas Instruments, the AN/APS-73 built by Goodyear, and Goodyear's AN/APQ-102. This latter system was the first operational unit, and was used in Air Force RF4C aircraft. It has a wavelength of 3.0 cm, utilizes an optical data processor, and produces imagery with fifteen meters resolution.<sup>42</sup> Areas of coverage vary between

---

<sup>40</sup>Robert G. Reeves, p. 42.

<sup>41</sup>Ibid.

<sup>42</sup>Ibid., p. 43.

the different systems. Some K-band systems have a range of sixteen to one hundred sixty kilometers per sweep.<sup>43</sup> The various X-band systems cover from six to ninety-two kilometers per sweep (Figure 10).<sup>44</sup> In the majority of systems, a ground distance of three-fourths to two and one-half nautical miles directly below the aircraft is not covered and is referred to as the radar holiday.<sup>45</sup>

Imagery scale also varies greatly from system to system and is often a characteristic of the mode of operation or the area being scanned. SLAR imagery is usually presented at scales from 1:1,000,000 to 1:100,000. When operating at 30,000 feet, the AN/APQ-56 SLAR system obtains imagery at a scale of 1:400,000.<sup>46</sup> Often the scale in range and azimuth will vary, however, the AN/APQ-102 and GEMS sets produce imagery at a constant scale of 1:400,000.<sup>47</sup>

Dealing with SLAR imagery and its interpretation requires care. Because of its nature, SLAR does not present a direct record of the ground pattern, but rather a record of the reflections of the earth's

---

<sup>43</sup>McCoy, p. 495.

<sup>44</sup>Dellwig, et al., Radar Remote Sensing, p. 16.

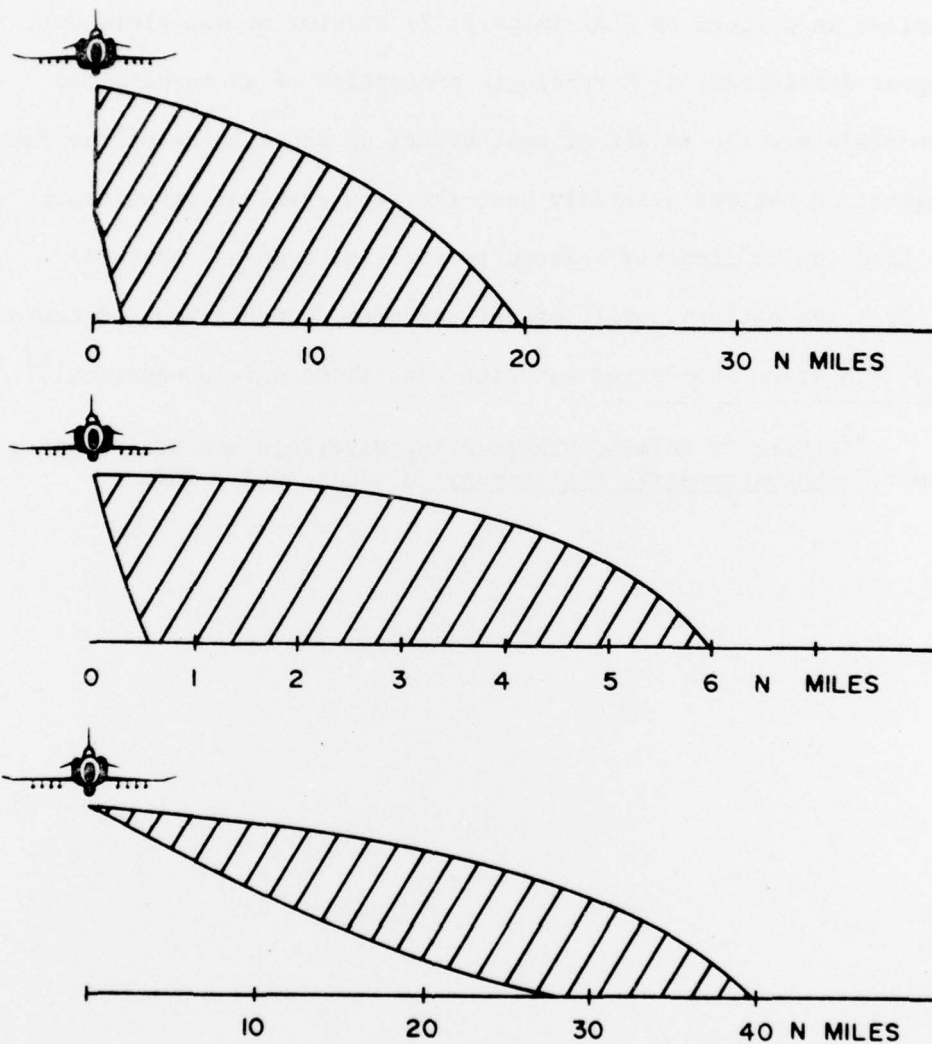
<sup>45</sup>G. P. de Loor, "Possibilities and Uses of Radar and Thermal Infrared Systems," Photogrammetria 24 (1969): 49.

<sup>46</sup>Jay H. Simons, "Some Applications of Side Looking Airborne Radar," in Proceedings of the 3rd Symposium on Remote Sensing of the Environment (Ann Arbor, Michigan: University of Michigan, 1965), p. 562.

<sup>47</sup>Naval Reconnaissance and Technical Support Center, Image Interpretation Handbook, Vol. 1 (Washington, D.C.: U. S. Government Printing Office, 1967), p. 3-45.

Figure 10<sup>48</sup>

TYPICAL LATERAL SLAR COVERAGES



<sup>48</sup> Multisensor Reconnaissance, pp. 3-4.

surface. It is not a photograph of the terrain. Thus, the principles of interpretation recommended by Robert Holmes should be kept in mind. These are: 1) Similar ground materials will appear similar in pattern on SLAR imagery; 2) Dissimilar materials will appear dissimilar; 3) Morphologic properties of unconsolidated materials are the result of weathering; 4) Broad areas of the same vegetation pattern generally have the same physical properties; 5) Land use is directly related to material type and texture; 6) Drainage patterns will reflect porosity, composition and texture; and 7) Surface boundaries coincide with lithologic boundaries.<sup>49</sup>

<sup>49</sup>Robert F. Holmes, "Engineering Materials and Side Looking Radar," Photogrammetric Engineering 33 (July 1967): 768.